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Toftum, Jørn; Thorseth, Anders; Markvart, Jakob; Logadóttir, Ásta

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# Occupant response to controllable LED lighting

Jørn Toftum<sup>1,\*</sup>, Anders Thorseth<sup>1</sup>, Jakob Markvart<sup>2</sup>, Astá Lógadóttir<sup>2</sup>

<sup>1</sup> Technical University of Denmark, Copenhagen, Denmark

<sup>2</sup> Danish Building Research Institute, Aalborg University, Copenhagen, Denmark

\*Corresponding email: [jt@byg.dtu.dk](mailto:jt@byg.dtu.dk)

## SUMMARY

At three different ambient temperatures, human subjects were exposed to correlated colour temperatures (CCT) in the range 2750 to 6230 K at an illuminance of 1000 lux. Significant associations were found between CCT and thermal sensation and between CCT and perceived stuffiness of the air.

## KEYWORDS

Correlated Colour Temperature, thermal sensation, perceived air quality, hue heat hypothesis.

## 1 INTRODUCTION

LED technology that allows for control of illumination and colour temperature is currently introduced in many buildings, mostly due to its low energy use. In addition to energy efficiency, controllable LED lighting potentially may stimulate occupants' perception of not only lighting, but also other aspects of the indoor environment, such as the thermal conditions or the air quality (e.g. Fanger et al. 1977, Winzen et al. 2014, Huebner et al. 2016). Even though findings in both older and newer literature are somewhat ambiguous, they generally seem to support the hypothesis that visual stimuli, in addition to parameters related with the body's heat balance, may affect thermal perception. This indicates that controllable LED lighting may expand the temperature interval that building occupants find comfortable and thereby reduce the use of energy to heat and cool buildings. This study attempted to quantify associations between CCT of LED lighting and thermal comfort and perceived air quality at temperatures on the upper and lower boundary of the summer and winter thermal comfort envelopes, respectively, and at a temperature optimal for winter comfort.

## 2 METHODS

Experiments were carried out with 44 human subjects (28 male and 16 female) seated in a controlled environment chamber. The lighting system in the chamber contained cold-white and warm-white diodes that could be dimmed separately to achieve CCTs in the range from 2746 K to 6231 K. Illuminance was kept constant at 1000 lux. At constant room temperature, the CCT was varied smoothly between plateaus at a rate that was imperceptible to the subjects. In balanced order, subjects were exposed to CCTs that varied from 2750 K to 6230 K and back to 2750 K or from 6230 K to 2750 K to 6230 K. Each exposure included five periods lasting either 5 or 10 min at constant CCT during which questionnaires were completed. Experiments took place at three different operative temperatures at the lower boundary of the winter comfort envelope (19°C), at the winter comfort temperature (22°C), and at the upper boundary of the summer comfort envelope (27°C) (ISO 7730-2005). Clothing insulation corresponded to standard summer (~0.5 clo) or winter (~1 clo) conditions.

During the experiments, CCT, operative temperature, relative humidity, and the CO<sub>2</sub> concentration were measured, and subjects completed five identical questionnaires. The analysis focused on two questions related with thermal sensation measured with a continuous 7-pt scale (ISO 7730-2005) and the perception of the air quality as measured with a categorical 5-pt scale ranging from Stuffy to Fresh. The association between CCT and thermal sensation was

analysed in a mixed-effects model adjusted for time, clothing insulation, measured operative temperature, and with subject as random factor. The association between CCT and air stuffiness was analysed in a generalized estimating equation model (GEE) adjusted for CO<sub>2</sub> concentration and time. Both models used an exchangeable covariance structure to account for intra-subject correlation between questionnaires.

### 3 RESULTS AND DISCUSSION

As expected, subjects' mean thermal sensation approximated slightly cool at 19°C, neutral at 22°C and slightly warm at 27°C (Figure 1a). The air was perceived as being more stuffy at 27°C than at 22°C or 19°C (Figure 1b), despite comparable CO<sub>2</sub> levels in the chamber air.

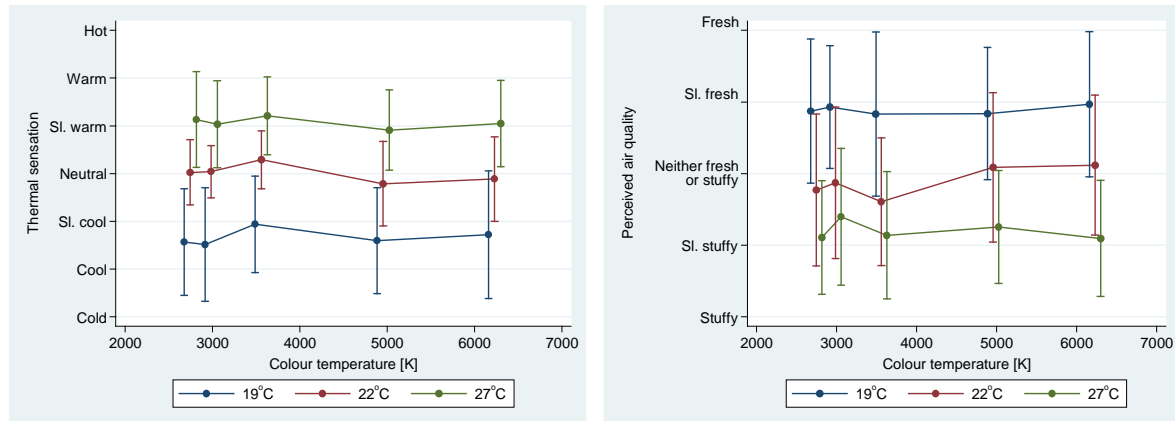


Figure 1. Association between the mean thermal sensation and the CCT (a-left) and between the mean perceived air stuffiness and CCT (b-right). Error bars indicate standard deviations.

The initial hypothesis was that the effect of CCT on subjective perceptions would be most pronounced on the boundaries of the comfort zone (19°C and 27°C), but at these temperatures the responses were not associated with the CCT. Therefore, the following summarizes only results of the statistical analyses of experiments at 22°C. When adjusting for covariates and random subject effects, the association between CCT and thermal sensation was significant with an effect estimate of -0.000992 (scale units)/(K CCT) ( $p < 0.01$ ; mixed effects model). This corresponds to a difference in mean thermal sensation of 0.35 scale units at the difference between the minimum and maximum CCT applied. Likewise, the air stuffiness improved 0.4 scale units in the same CCT range ( $p < 0.01$ ; GEE).

These findings were achieved under well-controlled conditions in a test chamber without interference from daylight or light from computer monitors that will be present in most office environments. Next step is therefore to repeat the study in a real-world setting to evaluate if CCT, also in practice, can modulate thermal comfort and other subjective responses.

### 4 ACKNOWLEDGEMENT

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